STEPHEN HALES, THE PHYSIOLOGIST.

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A few weeks ago we saw that Stephen Hales was to be re- [232]
garded not only as a clergyman but also as a philanthropist and a scientist. At that time it was stated that his "contributions to animal physiology were many and important" but that "a discussion of this part of Hales' work would be reserved for another communication."

The account of Hales' work on this subject is contained in the Statical Essays: in the chapter of Vol. I describing the experiments "which show in how great proportion Air is wrought into the composition of animal, vegetable and mineral substances," but chiefly in that part of Vol. II which is entitled "Haemostaticks."

In presenting this subject no attempt has been made to give even a sketch of the whole field of physiology as it appeared to Hales or was affected by his researches. The purpose of the writer being to give some insight into the character rather than into the scope of the work, he has selected certain passages from the "Haemostaticks" and has merely supplemented these quotations with such explanations and comments as have seemed to him needful or appropriate.

"What I had first intended[2] only as additional Observations and Experiments to the first Volume, is now grown to the Size of another Volume, so fruitful are the Works of the great Author of nature in rewarding, by farther Discoveries,

[1] Read before the Johns Hopkins Hospital Historical Club, May 11, 1903.

[2] Preface: Hæmostaticks, 1733.

[232] the Researches of those *who have pleasure therein:* We can never indeed want for Matter for new Experiments; and tho' the History of Nature as recorded by almost innumerable Experiments, which have been made within the compass of a Century, be very large, yet the Properties of Bodies are so
[233] various, and the different Ways by which they may be examined so infinite, that 'tis no wonder that we as yet have got little farther than the Surface of Things: Yet ought we not to be discouraged, for tho' we can never hope to attain to the compleat Knowledge of the Texture, or constituent Frame and Nature of Bodies, yet may we reasonably expect by this Method of Experiments, to make farther and farther Advances abundantly sufficient to reward our Pains.

"And tho' the Method be tedious, yet our Abilities can proceed no faster; for as the learned author of the *Procedure of human Understanding* observes, pag. 205, 206, 'All the real true Knowledge we have is entirely *experimental,* in so much that, how strange soever the Assertion seems, we may lay it down as the first fundamental and unerring Rule of Physicks, *That it is not within the compass of human Understanding to assign a purely speculative Reason for any one Phenomenon in Nature.*' "

"As the animal Body[3] consists not only of a wonderful texture of solid Parts, but also of a large proportion of Fluids, which are continually circulating and flowing, thro' an inimitable Embroidery of Blood-Vessels, and other inconceivably minute Canals: And as the healthy State of the Animal principally consists, in the maintaining of a due *Equilibrium* between those Solids and Fluids; it has, ever since the important Discovery of the Circulation of the Blood, been looked upon as a Matter well worth the inquiring into, to find the Force and Velocity with which these Fluids are impelled; as a likely means to give a considerable Insight into the animal OEconomy."

"Several ingenious Persons have from time to time, attempted to make Estimates of the Force of the Blood in the Heart and Arteries, who have as widely differed from each

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[3] Introduction. 1. Hæmostaticks, 1733.

other as they have from the Truth, for want of a sufficient [233]
Number of *Data* to argue from: Had Persons of their Abilities been more careful, in the first Place to get what Insight they could into the Matter, as far as a regular Series of proper Experiments would have informed them, they would then doubtless have been furnished with more and more proper *Data* whereon to found their Calculations, which would have brought them much nearer to the Truth."

"It may not be improper[4] here to take notice, that being about twenty-seven years since, reading the unsatisfactory conjectures of several, about the cause of muscular motion, it occurred to me, that by fixing tubes to the arteries of live animals, I might find pretty nearly, whether the blood, by its mere hydraulic energy, could have a sufficient force, by dilating the fibres of the acting muscles, and thereby shortening their lengths, to produce the great effects of muscular motion. And hence it was, as I mentioned in the preface to Vol. I, that I was insensibly led on from time to time into this large field of statical and other experiments." How this hydraulic energy was measured is described in the following classical experiments which have given us the Hales manometer.

"In December[5] I caused a *mare* to be tied down alive on her back; she was 14 hands high, and about 14 years of age; had a fistula on her withers, was neither very lean nor yet lusty: having laid open the left crural artery about 3 inches from her belly, I inserted into it a brass pipe whose bore was $\frac{1}{6}$ of an inch in diameter; and to that, by means of another brass pipe which was fitly adapted to it, I fixed a glass tube, of nearly the same diameter, which was 9 feet in length: then untying the ligature on the artery, the blood rose in the tube 8 feet 3 inches perpendicular above the level of the left ventricle of the heart: . . . when it was at its full height, it would rise and fall at and after each pulse 2, 3, or 4 inches; . . . ."

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[4] Exp. IX, 23. Hæmostaticks. Where, as in this case, the year of publication is not given it is to be understood that the edition of 1769 is meant. This second edition differs but little from the first except in the less frequent use of capitals.

[5] Exp. I, 1.

[233] "Then [6] I took away the glass tube, and let the blood from the artery mount up in the open air, when the greatest height of it's jet was not above 2 feet."

"I measured [7] the blood as it run out of the artery, and after each quart was run out, I refixed the glass tube to the artery to see how much the force of the blood was abated; this I repeated to the 8th quart, and then its force being much abated, I applied the glass tube after each pint had flowed out: . . . ."

This experiment was repeated on two other horses and the relation of the blood pressure to the amount of the blood removed was shown in a series of tables. The technique employed by Hales in these experiments is not without interest: "In December [8] I laid a common field gate on the ground, with some straw upon it, on which a white *mare* was cast on her right side, and in that posture bound fast to the gate: . . ." It was of course difficult to keep the manometer in place when the animal struggled and as there was no rubber tubing in those days with which a flexible joint could be made for the pieces of "brass pipe" some other method had to be devised. Accordingly we read that in one of these experiments Hales joined the brass pipe to the glass tube by means of the windpipe of a goose.[9]

A necropsy on one of the horses showed that "There [10] might be about two quarts and three-quarters of blood left in the large veins, which, with what was drawn out at the artery, makes five wine gallons, which at 221 cubick inches to the gallon, amounts to 1105 cubick inches, or 42.2 pounds; which, at a low estimation, may be reckoned the quantity of current blood in the horse; there is, doubtless, considerably more, but it is not easy to determine how much." When these calculations are expressed in modern terms we find that, according to Hales, the total amount of blood in the horse is "doubtless considerably more" than 4.6 to 5.2 per cent. of the body weight while the lethal hemorrhage is about 2.7 per cent. of the body weight.

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[6] Exp. I, 3. [7] Exp. I, 4. [8] Exp. III, 1.
[9] Exp. III, 6. [10] Exp. I, 13.

In one of these horses the pressure in the jugular vein was determined. When the animal was quiet this amounted to only 12 inches but this rose to 52 inches when the animal struggled.[11] [234]

Experiments similar to the above were performed upon other animals namely, a sheep, a doe and twenty dogs, for, says he, "whatever experiment I principally intended to make on any dog, I usually began with fixing a tube first to the jugular vein and then to the carotid artery."[12]

Hales then filled a number of hearts with melted beeswax,[13] then cutting away the tissue, he measured the volume and the superficial area of the casts. With these two factors and knowing the blood pressure, the heart rate, the diameter of the aortic orifice and of the aorta itself, he calculated for horses, oxen, deer, sheep, dogs and man, the mean velocity of the blood in the aorta, the velocity of the systolic output and the total amount of pressure sustained by the heart at the beginning of each contraction. Into all these calculations the capacity or volume of the heart entered as a factor; a factor which, as has been said, Hales determined by the use of melted wax. Now as a matter of fact, the volume of the heart cannot be determined in this or in any other way with any degree of accuracy so that all his calculations are more or less incorrect. But in spite of these inaccuracies we see that Hales had advanced one step beyond Harvey, in that the results of the latter are qualitative whereas those of Hales are quantitative.

That Hales possessed a clear conception of the nature of the blood pressure and of the factors upon which it depends, is readily seen from the following passage. After discussing the rate of the output of the heart he continues: "Now this velocity[14] is only the velocity of the blood at its first entering into the *aorta*, in the time of the *systole;* in consequence of which the blood in the arteries, being forcibly propelled, with an accelerated *impetus,* thereby dilates the canal of the arteries, which begin again to contract at the instant the *systole* ceases: by which curious artifice of nature the blood is carried on to

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[11] Exp. III, 2-4, also table on p. 42.

[12] Exp. VII, 1.

[13] Exp. III, 11 &c.

[14] Exp. III, 26.

[234] the finer capillaries, with an almost even tenor of velocity, in the same manner as the spouting water of some fire engines is contrived to flow with a more even velocity, notwithstanding the alternate *systoles* and *diastoles* of the rising and falling *embolus* or force . . . ." And again, "For tho' the velocity[15] of the blood at its first entrance into the *aorta,* depends on the proportion the area of its orifice bears to the quantity thrown into it at each *systole,* and also on the number of these *systoles* in a given time: yet the real force of the blood in the arteries, depends on the proportion, which the quantity of the blood thrown out of the left ventricle in a given time, bears to the quantity which can pass thro' the capillary arteries into the veins in that time."

"The force of the blood[16] in the veins and arteries is very different, not only in animals of different species but also in animals of the same kind; and that not only in those of different sizes and weights, but also in dogs of the same size and weight; and even in the same animal the force of the blood in its vessels is continually varying, according to the different kinds and quantities of food, the various distances of the time after taking food, the more or less plethoric state of the blood vessels, also from exercise, rest, different states of vigor or vivacity of the animal, and many other circumstances, which may conduce to vary the force of the blood: for the healthy state of animals is not confined to the scanty limit of one determinate degree of vital vigor in the blood: but the all-wise Framer of these admirable machines has so ordered it, as that their healthy state shall not be disturbed by every little variation in this force, but has made it consistent with a very considerable latitude in the variation of it . . . ."

Hales fully appreciated the difference between lateral and end pressures, for, referring to the fact that the brass pipe was inserted directly into the carotid or crural artery, he remarks, "It may be objected[17] to this method of estimating the force of the blood that by thus fixing tubes in these large veins and arteries, the source of a considerable stream of blood was for the time stopped; and that consequently the force of the blood

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[15] Exp. IX, 13. [16] Exp. VII, 2. [17] Exp. VII, 5.

must be proportionally increased in the veins and arteries." [234] In order to obtain lateral pressures Hales adopted the following ingenious device. He placed the blood vessel between two grooved pieces of wood which were then cemented together and to the vessel by means of warm pitch. One of these pieces of wood had had a hole bored in it. Through this he punctured the vessel and screwing a tube into the hole, he allowed the blood to mount up into it.

That Hales understood the relation of the velocity of the blood to the area of the stream bed; that, in other words, he applied Leonardo da Vinci's law to the circulation is seen in the following. "The arteries[18] continually sending off innumerable branches, the sum of whose orifices is considerably larger than the main stems, hence the velocity of the blood must be proportionately rebated." Nor did he fail to allow for the effect of hydrostatic pressure, for he writes, "when the animal[19] stands on its legs, a column equal to the perpendicular height of the animal, must be added to the several heights of the blood in the glass tubes, in order to estimate the force with which the blood presses against the coats of the blood vessels, at the lower parts of the body, and so in proportion for any other part that is higher."

In the following series of experiments Hales endeavoured to show that the greatest resistance offered to the blood flow is that which occurs in the capillary area.[20] He slit the gut of a freshly killed dog along its greater curvature and running in by way of the aorta "blood-warm" water under a column of pressure (4½ feet) equal to the pressure exerted by the heart, he found that the fluid only oozed out. It required in fact six minutes for 300 cubic inches of the liquid to pass through the gut. He then cut away the guts along the line of their mesenteric attachment and found that the time now re- [235] quired was only two minutes, while on cutting the vessels close to the aorta, the time was still farther reduced to 0.3 minutes or only 0.05 of the time which had originally been required for the same quantity of liquid to pass through the slit gut.

The vessels of the slit gut then offer considerable resistance

[18] Exp. VIII, 23. [19] Exp. VII, 8. [20] Exp. IX.

[235] to the flow of blood, but the resistance offered by the gut in the intact animal must be far greater for the following reasons.[21] If 300 cubic inches of blood passed through the intact gut in six minutes, then it may be shown that at each systole one-half of the blood in the heart must pass to the gut. If now we compare the weight of the gut with that of the other blood-containing tissues, we see that the intestine should receive only 1-26 of the heart's output at each systole. In other words the intestine in the living animal offers thirteen times as much resistance to the passage of blood as in the experiment above described. The reasons for this great difference are:[22]

(1) The greater fluidity of water as compared with blood.

(2) The absence of the back pressure of the veins in the one case and its presence in the other.

(3) The greater distensibility of the dead arteries.

(4) In the case of the slit gut the fluid is no longer obliged to pass through the fine capillaries but runs out through the larger vessels which have been severed.

It will be remembered that the origin of these hydraulic and hydrostatical experiments was the desire to know if the blood possessed force enough to bring about the phenomenon of muscular contraction. By subtracting from the pressure in the smaller arteries the pressure in the corresponding veins, Hales obtained a figure which represented the loss of force sustained by the blood in passing through the capillaries. Though the sum total of this force was of course considerable, he found that the amount lost at any one point was entirely inadequate to account for muscular action.[23] Hence he thought that it was to the animal spirits that we must look for an explanation. Not satisfied like so many of his contemporaries with invoking the aid of these hypothetical spirits, and then considering the question solved, Hales suggests that animal spirits may be in some way related to electricity.[24] He therefore tried to demonstrate electrical properties in blood. In this, however, he failed.[25]

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[21] Exp. IX, 6. [22] Exp. IX, 7. [23] Exp. IX, 16.
[24] Exp. IX, 18-19. [25] Exp. XIII.

One of the most interesting series of experiments undertaken by Hales was that pertaining to the effects of various substances and of water at various temperatures on the calibre of the arterioles or as he calls them "capillary arteries." "I took a young spaniel dog,[26] . . . opened his *thorax* and *abdomen,* and having fixed a glass tube, which was 4 + ½ feet high, to the descending aorta, I then slit open his guts, from end to end . . . . Then having poured blood-warm water on them, and covered them with a folded cloth dipped in the same water, warm water was poured into the tunnel [attached to the tube]; which when it had subsided to a mark on the lower part of the glass tunnel, 18 cubick inches of warm water were immediately poured in, out of a pot which held just that quantity: the time that it was running thro' the fine capillary arteries was measured by a pendulum that beat seconds." [235]

"I first poured in seven pots full of warm water, the first of which passed off in 52 seconds, and the remaining six gradually in less time to the last, which passed in 46 seconds."

"I then poured in five pots of common brandy, or unrectified spirit of malt, the first of which was 68″ in passing, the last 72″."

"I then poured in a pot of warm water which was 54″ in passing."

"Hence we see that brandy contracts the fine capillary arteries of the guts, and that water soon relaxes them again, ..."[27]

A decoction of Peruvian bark[28] contracted the vessels. A decoction of "Chamomel flowers"[29] caused some constriction but not so much as cinnamon-water with which the constriction is very marked indeed. Pyrmont water[30] was also very effective.

Hales considered these experiments to be of importance as

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[26] Exp. XV, 3-7.

[27] Hales also compared the effect obtained with warm water and with cold pump water. The former flowed readily through the gut requiring only 18 seconds for the passage, while the latter caused a marked constriction and took 80 seconds to pass through the gut.

[28] Exp. XVI. [29] Exp. XVII. [30] Exp. XVIII.

[235] indicating the probable action of these substances in the living body "tho' it is not to be imagined,[31] that the effects are so sudden and great in a live animal, as in these experiments; because in a live animal, the several fluids which are taken in, are more gradually and in smaller proportion blended with the blood." "'Tis probable,[32] that such things as constringe the vessels in any degree, do also proportionately increase the force of the arterial blood, and thereby invigorate the animal. But those who much accustom themselves to drink strong spirituous liquors, do thereby destroy the tone of the fibres of their vessels, by having them thus frequently, suddenly contracted, and so soon relaxed again; which makes them like the horse-leech, be ever longing after and thirsting for more and more, thereby to regain again the tensity of their too relaxed fibres.

"After having seen [33] many proofs of the great force of the blood in the arteries, and also in the veins, when an animal exerts its strength; I thought it might not be a useless inquiry to examine the strength of the coats of those vessels."

"I poured [34] into an inverted glass syphon some mercury, so as to have the shortest leg, which was hermetically sealed, filled within four inches of the top; to the other open end of the syphon I fixed, by means of a brass pipe, one end of the right carotid artery of a small spaniel dog, and to the other end of the artery was fixed a condensing syringe. Then
[236] placing the artery in water to see whether it leaked, I impelled the air in to such a degree as made the mercury compress the air between it and the sealed top of the tube into so small a compass, as showed by estimation, the force to be equal to a column of water 190 feet high, or equal to the weight of 5.421 atmospheres; with this force the artery burst at once, but no air passed thro' its coats before it burst."

Experiments similar to the above were repeated on the arteries and veins of various animals. Hales then estimated the normal variations in the blood pressure in both arteries and veins and observed the wide margin which exists between

[31] Exp. XVIII, 4.
[32] Exp. XVIII, 5.
[33] Exp. XXII, 1.
[34] Exp. XXII, 2.

the maximum pressure of the blood and the breaking point of [236]
the vascular walls. These results seem to have impressed him very much for he wrote "We see[35] in these instances the great strength of the coats of these vessels; what great reason have we therefore with thankful hearts to say to our Creator, as holy Job did, when he contemplated on the wonderful frame and strength of his body, Job X. 2., *Thou hast* not only *fenced me with bones and sinews,* but hast also effectually secured the vital fluid in such strongly wrought channels, as are proof against its most lively and vigorous sallies, when either agitated by the different passions, or by strong and brisk actions of the body!"

Surprised by the results of his experiments on the strength of the arteries and veins, Hales proceeded to try similar experiments on other tissues. "I took[36] the instep bone of the hinder leg of a calf" fastened one end by a cord to the threshold of a door case, then with an iron bar as a lever attached to the other end pulled the bone apart at the epiphysis. "I found the tenacity and resistance of this joining to be equal to 119 lbs., when the periosteum was removed." It required 550 lbs. to pull apart the bone of the other leg in which the periosteum had not been removed. Subtracting 119 from 550, we get 431 which is then the strength of the periosteum.

"As a force[37] equal to five hundred and fifty pounds was found requisite to separate the above-mentioned joining *symphysis,* so in the growth of the bone lengthwise at that joining nature must exert a like power; not that we are to suppose that the growing fibres are forcibly stretched out at each end, ... But yet the whole sum of the power must be superior to the resistance of all the fibres which connect this juncture."

"I made[38] hydraulic and hydrostatical Experiments not only on the arteries and veins, but also on the intestinal tubes; by affixing, in like manner, tubes of different heights to each end of them, while they were warm.

"I fixed[39] a tube to the gullet of a dog and then poured in

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[35] Exp. XXII, 12. [36] Exp. XXII, 29. [37] Exp. XXII, 33.
[38] Exp. XXIII, 1. [39] Exp. XXIII, 2.

[236] water, till the stomach was so full, that the water in the tube stood 36 inches perpendicular height above the stomach; which force burst it lengthwise in its upper part near the pilorus, where it was but 7 + ½ inches of circumference: yet no water was impelled through the *pilorus* with this force, though in some other like experiments it has run thro' there into the guts. Another dog's stomach burst in the larger left part of it, when the height of the column of water was but 30 inches."

"On measuring[40] the distention of the stomach in another dog, I found its whole surface equal to 80 square inches, which multiplied into 36, the height of the water in the tube, gives 2880 cubick inches of water, or 104 pounds weight of water, which pressed against the sides of the stomach: and allowing the area of the greatest transverse section of the stomach to be equal to 30 square inches, then the pressure of the water against the fibres of the stomach in that section, when it burst, will be 39 pounds. Which shows how greatly Borelli and Pitcairn were mistaken, when they estimated the force of the fibres of the stomach to be equal to 12,951 pounds; since we may with good reason conclude that the force of those fibres cannot in the live animal be greater than the force which will tear them asunder, as soon as dead. Neither can the pressure of the *diaphragm* and of the muscles of the abdomen on the stomach, be in our utmost straining greater than a weight of mercury two inches deep, and of the breadth of all their areas, as I have shown under Experiment CXVI, Vol. I, p. 270. And that the sum of the compressure of the muscles of the *abdomen* and *diaphragm*, and so also of the stomach on its contents, is not nearly equal to the weight of two inches deep of mercury, is evident from the Appendix,[41] Exper. VII of this Vol. II, where it was found by a mercurial gage fixed in the nose of large pair of smith's bellows, that the most forcible blast of them will scarcely raise mercury two inches high in the gage: And since such a blast of

[40] Exp. XXIII, 3.

[41] "Appendix containing Observations and Experiments relating to several Subjects in the First Volume."

wind is manifestly much greater than the most forcible puff [236]
of wind, which is belched out of a distended stomach; it is hence evident, that the stomach, even in that much distended case, does not compress what is contained in it with near that force."

"If we suppose[42] the surface of a full stomach to be equal to 80 square inches, and that its contents are compressed by the action of it, together with that of the *diaphragm*, and the muscles of the *abdomen*, with a force equal to one inch in depth, then the whole pressure on its contents will be equal to 39 pounds, which is nearly the weight of 80 cubick inches of mercury: but as this seems to be too great a force by comparing the velocity with which wind rushes out of bellows, which force is sufficient to raise mercury an inch in the gauge; so I believe half that force, *viz.*, about 20 pounds, would come nearer to the pressure of the aliments in a full stomach."

"Now[43] so small a compressure can have very little effect in promoting the digestion of the aliments: which is therefore with good reason principally attributed to the concurrence of several other causes; such as mastication and comminution with the teeth, and mixture first with *saliva* (which [237]
is a leaven full of elastic air), and afterwards with the fluid, which is in plenty separated from the glands of the stomach; . . . . "

Regarding the function of the lungs[44] Hales was somewhat in doubt, but foremost he placed their refrigerating action. One is accustomed to see this function of the lungs discussed by the older writers in a more or less hazy and indefinite way. Hales, however, carefully calculates, or rather has calculated for him, the exact amount of this refrigeration. Having determined the quantity of blood passing through the lungs per minute, the amount of air breathed during the same time, and finally the difference in the temperature of the inspired and the expired air, he communicated these data to Dr. Desaguliers and Mr. Ch. de Labely. These gentlemen then showed that as much heat is lost in two minutes by way of

[42] Exp. XXIII, 4. [43] Exp. XXIII, 5. [44] Exp. XIII, 14.

[237] the lungs as would be required to raise all the blood in the body 0.101928 of a degree, or conversely if one holds his breath for two minutes, "as Gano the trumpeter can," the temperature of his blood will rise 0.101928 of a degree in that time.

When shaken, blood becomes florid, it also becomes florid in passing through the lungs, hence it may be, Hales suggests, that the blood is shaken by the movements of the lungs, but why that should be of any value he was unable to state. He concludes his discussion of the functions of the lungs with the following paragraph: "It is probable[45] also, that the blood may in the lungs receive some other important influences from the air, which is in such great quantities inspired into them. It has long been the subject of inquiry of many, to find of what use it is in respiration, which tho' it may in some respects be known, yet it must be confessed that we are still much in the dark about it."

The "Hæmostatics" is without form or order; in this treatise Hales simply rambles on and on, each experiment suggesting another, so that he was led almost imperceptibly to study a great many physiological phenomena.

The above extracts and abstracts have been given in the hope of imparting some idea of the experimental methods employed by Hales and of the character of the reasoning to which he resorted in his study of animal physiology. The "Haemostaticks," however, contains much more than this. On the title page of Volume II of the Statical Essays stands a quotation from the Instauratio Magna: "True and living natural philosophy upon which the science of medicine is built is a thing to be desired." Having laid a foundation Hales began to build, to apply his physiological lore to medical problems. Hence the "Essays" abound in practical suggestions, some of which are excellent, and in theoretical explanations, most of which are worthless. But one must not criticise him too severely. No one appreciated better than he the proper function of speculation as is shown again and

[45] Exp. XIII, 36.

again in his writings. "In natural Philosophy, we cannot [237]
depend on any meer Speculations of the Mind; we can only with the Mathematicians, reason with any tolerable Certainty from proper *Data,* such as arise from the united Testimony of many good and credible Experiments."

"Yet[46] it seems not unreasonable on the other hand, tho' not far to indulge, yet to carry our Reasonings a little farther than the plain Evidence of Experiments will warrant; since at the utmost boundaries of those Things which we clearly know, there is a kind of Twilight cast from what we know, on the adjoining Borders of *Terra incognita,* it seems therefore reasonable in some degree to indulge Conjecture there; otherwise we should make very slow Advances in future Discoveries, either by Experiments or Reasoning: For new Experiments and Discoveries do usually owe their first Rise only to lucky Guesses and probable Conjectures, and even Disappointment in these Conjectures, do often lead to the Thing sought for: Thus by observing the Errors and Defects of a first Experiment in any Researches, we are sometimes carried on to such fundamental Experiments, as lead to a large Series of many other useful Experiments and important Discoveries."

The debt which medicine owes to physiology is not so much for its facts as for its methods; and although it was left for another[47] to introduce the method of experiment into medicine, still in the evolution of this method Hales played an important rôle. It is, therefore, because his researches are among the earliest examples of *quantitative* work in the field of animal physiology that they merit our attention and indeed our admiration.

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[46] Introduction: Hæmostaticks, 1733. [47] François Magendie.